Rethinking Ecology
PERSPECTIVES

Rethinking Ecology 6 65–92 (2021)
doi: 10.3897/rethinkingecology.6.64103
http://rethinkingecology.pensoft.net

Ecologist engagement in translational science is imperative for building resilience to global change threats

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Academic editor: J.Martínez-López | Received 9 February 2021 | Accepted 12 April 2021 | Published 23 April 2021

Citation: Rubert-Nason K, Casper AMA, Jurjonas M, Mandeville C, Potter R, Schwarz K (2021) Ecologist engagement in translational science is imperative for building resilience to global change threats. Rethinking Ecology 6: 65–92. https://doi.org/10.3897/rethinkingecology.6.64103

Abstract

The causes and consequences of global change are well-documented, as are mitigation and adaptation strategies. However, human actions continue to fail in building adequate socio-ecological resilience to the accelerating threats of global change. Translational science, which focuses on connecting scientific research to human benefits, is imperative to building resilience to a confluence of global change threats because it brings the implications of theory and empirical research into practice. Translational ecology, an approach to knowledge co-creation that is grounded in equitable, inclusive, empathetic, and just partnerships among administrators, policy makers, scholars, practitioners, and the public, has immense potential to bring about the rapid and expansive social, ecological and political changes necessary to build resilience to global change threats. Here, we articulate a need for greater engagement of ecologists and other professionals in translational initiatives addressing seven major resilience building challenges, and propose a framework that lowers barriers to participation and promotes stronger relationships among stakeholders. We recommend specific actions that ecologists can take based on their situation, as well as evidence and demonstrated need, to foster resilience building through their contributions to communication, policy, education, knowledge creation, leadership, and service as role models. We conclude with an urgent call for expansive engagement of ecologists and other professionals in initiatives that combat misinformation, partner equitably with communities in knowledge creation, cultivate empathy and compassion, bolster public trust in science, and ultimately build decentralized communities of practice that enable rapid and high-impact responses to global change.

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Keywords
community partnerships, education, policy, theory of change, translational ecology

Translational science is imperative to building resilience to global change threats – An urgent call to action

Translational science, which focuses on connecting scientific research to human benefits, is imperative to building resilience to a confluence of global change threats because it brings the implications of theory and empirical research into practice (Gunderson and Holling 2001; Biggs et al. 2015; Brown 2015; Chapin 2017; Enquist et al. 2017). Yet the potential of translational science has been limited by policies and cultural norms, as well as inadequate communication, funding, labor, training, and stakeholder engagement (Whitmer et al. 2010; Singh et al. 2014; Hallett et al. 2017). Successful implementation of translational science requires strategic planning, funding, incentivization, and equitable, inclusive partnerships that are attuned to the culture of diverse stakeholders. Many ecologists are uniquely positioned to engage in translational science because of their transdisciplinary skills in science, communication, and application. A strategic framework for implementing translational science, in which trained ecologists serve as liaisons between communities and administrative organizations is badly needed in order to build resilience in seven major categories of global change threats: landscape change, climate change, pollution, resource extraction and pollution, extreme events, biodiversity loss, and invasive species and emergent pathogens (Table 1).

Global change is an immediate, and accelerating, threat to humanity (e.g., Ripple et al. 2017, 2020; Ye et al. 2017; IPCC 2018; Li et al. 2018). Access to a livable climate, breathable air, potable water, food, energy, and other important resources is expected to become increasingly impaired during the current decade (2020–2030) (Ripple et al. 2017; Steffen et al. 2018; Brondizio et al. 2019), impacting human health and amplifying preexisting socioeconomic inequities (Schlosberg 2013; Agyeman et al. 2016; Chen et al. 2017a). Some highly industrialized nations (e.g., United States) have a per capita CO_2 emissions rate three times greater than the global average (World Bank 2014; Weidmann et al. 2020), and this pattern is anticipated to extend to other nations as they become more industrialized. Use of nonrenewable fossil and mineral resources masks supply deficits while accelerating buildup of wastes that degrade water, air and soil quality and alter climate. Air and water pollution is already ubiquitous, with measurable negative impacts on human, animal, plant, and ecosystem health (Colborn 1997; Ochoa-Hueso et al. 2017; Ye et al. 2017; Li et al. 2018; Mahalingaiah et al. 2018; Steffen et al. 2018; An et al. 2019). Exposure to pollution exacerbates effects of pathogens on human health, as observed with diseases such as SARS and COVID-19 (Cui et al. 2003; Wu et al. 2020). And land use and climate change have the potential to unleash additional novel pathogens (Anderson et al. 2004; U.S. Official News 2020). Biodiversity loss and land use change exacerbate the impacts of climate change

Table 1. Theory of change: A logic framework through which ecologist-community partnerships can synergistically amplify efforts to address seven resilience grand challenges.

Grand Challenge	Goal(s):	Strategy:	Indicators of Success
(Rationale)	Minimize impacts on human health, food security, and/or biodiversity by:	Leverage communication, policy, education, research, technology, and actions to:	(Assessments)
Landscape change (e.g., landscape modification, sea level rise)	Mitigating, and adapting to landscape changes	1) Sustainably manage landscape changes 2) Slow and adapt to unavoidable landscape changes	1) Decreased rate of anthropogenic landscape modification 2) Increased investment in infrastructure for mitigation of or adaption to landscape change
Climate change (warming and desertification)	Mitigating and adapting to climate change	1) Slow or stop climate change (e.g., decrease CO_2 emissions and increase uptake) 2) Enable mitigation of and adaptation to negative consequences of climate change	1) Stable or declining levels of atmospheric CO_2 and temperatures 2) Increased investment in mitigation/adaptation technologies and practices 3) Decreased expansion of deserts
Pollution (of soil, air, and water)	Mitigating, remediating, and/or adapting to pollution	1) Decrease new pollution inputs 2) Remediate existing pollution 3) Enable co-existence with pollution 4) Create networks of administrators, liaisons, and community members to execute rapid responses to pollutant releases	1) Geographical area occupied by landfills stops expanding 2) Decreased market shares of products with high potential to cause pollution 3) Increased investment in pollution remediation and adaptation 4) Decreased impacts of pollution on human health and biodiversity
Resource extraction and depletion (water, minerals, fossil fuels)	Managing resources sustainably	1) Prohibit resource extraction or require sustainable resource management 2) Implement technologies and practices necessary for sustainable resource management	Resource extraction rate approaches resource renewal rate or approaches zero for nonrenewable resources
Extreme events (e.g., fires, droughts, floods)	Creating resilient infrastructure, culture, and rapid/effective responses to extreme events	1) Build infrastructure that protects life and property from extreme events 2) Organize networks of administrators, liaisons, and community members who are prepared and willing to respond to extreme events	Following an extreme event, there are: 1) Smaller financial losses reported 2) Little or no loss of human life, food production, or biodiversity 3) Rapid, coordinated responses among administrators, liaisons, and community members
Biodiversity loss	Implementing conservation best practices, and mitigating environmental change impacts	1) Support a culture that values biodiversity 2) Train observers to identify signs of biodiversity loss 3) Encourage policies that adopt conservation best practices 4) Mitigate impacts of environmental change on biodiversity	1) Average global biodiversity loss declines or ceases 2) Local biodiversity stabilizes or increases
Invasive species and emergent pathogens	Identifying and slowing or stopping the spread of invasive species and pathogens	1) Train observers to identify signs of invasive species and pathogens 2) Acculturate public in best practices to prevent dispersion 3) Prepare networks of administrators, liaisons, and community members to execute rapid responses	For invasive species and emergent pathogens: 1) Identification is prompt 2) Dispersion is restricted 3) Impacts are rapidly mitigated

Assumptions:

1) Necessary technology and practices exist or can be developed.
2) It is feasible to form coalitions that engage in the recommended actions.
3) Widespread preparedness and available technologies enable actions to occur rapidly and expansively.

and pollutants and impair ecosystem services (Rands et al. 2010; Steffen et al. 2018; Brondizio et al. 2019; Chapin and Díaz 2020). Global change impacts both people and communities disproportionately, in part because of longstanding systemic inequities that disempower people, particularly those from the Global South, along with those of lower socioeconomic status and less access to political representation (Schlosberg 2013; Agyeman et al. 2016; Chen et al. 2017a; Sellers et al. 2019).

Immediate, expansive, and high impact actions are needed to build resilience in each of the seven categories of global change threats (Ripple et al. 2017, 2020; IPCC 2018). Substantial research, technological innovation, behavior change initiatives, and policy discourse have focused on mitigation of and adaptation to changes in climate, sea level, and toxic pollutants that are forecast by the year 2030 (e.g., NRC 2007; IPCC 2008; Lidskog and Waterton 2016; Chen et al. 2017b; Hawken 2017; IPCC 2018; Steffen et al. 2018; Brondizio et. al. 2019), as well as emergent pathogens (Cui et al. 2003; Wu et al. 2020). In response, expansive increases in production of renewable resources (e.g., forest products, wind and solar energy), reprocessing of existing resources (through recycling and restoration), decreases in resource consumption (especially fossil fuels), and the restoration and conservation of ecosystems are necessary to synchronize supply and demand, eliminate resource deficits and waste production, and maintain and restore ecosystem services (Rands et al. 2010; Tilman et al. 2017; Hawken 2017). Yet, even with immediate mitigation, the legacy of human impacts on climate, land, air, and water quality will be profoundly negative (e.g., Ripple et al. 2017, 2020). Increasing global temperatures, frequencies of extreme events (e.g., severe droughts and fires), and sea levels attributed to CO_2-mediated climate change, as well as increasingly widespread distribution of toxic pollutants, will require humans to revise their current practices of habitation, water use and food production (e.g., Calhoun 2005; IPCC 2018, Gardiner 2019).

Actions to date have failed to build adequate resilience to global change threats. Policies that are poorly-articulated, irrational, irrelevant, undermined by special interest groups, unenforced, or that lead to "climate gentrification" have impeded the implementation of resilience building technologies and practices (NRC 2009; Dilling and Lemos 2011; Parsons et al. 2015; Anguelovski et al. 2019). These policies foster a social climate that is counterproductive to resilience building, characterized by inequity, extensive misinformation, lack of trust in science, a perception of limited opportunities for authentic engagement in resilience building, as well as fatalism, apathy, and fear – and the effects are compounded by the anxiety triggered by climate disasters, resource shortages, and pandemics (McCright and Dunlap 2010). Deliberate efforts motivated by the self-interest of individuals and institutions (e.g., extraction of fossil and mineral resources, manufacture of persistent pollutants; McCright and Dunlap 2010; Fake News 2017; Zimmer 2018) continue to undermine resilience initiatives and to discredit fundamental research. Consequently, human society as a whole continues engaging in actions that damage Earth and impair future generations' chances of survival, despite a preponderance of evidence demonstrating the negative consequences of those actions, and the possibility of implementing more sustainable practices.

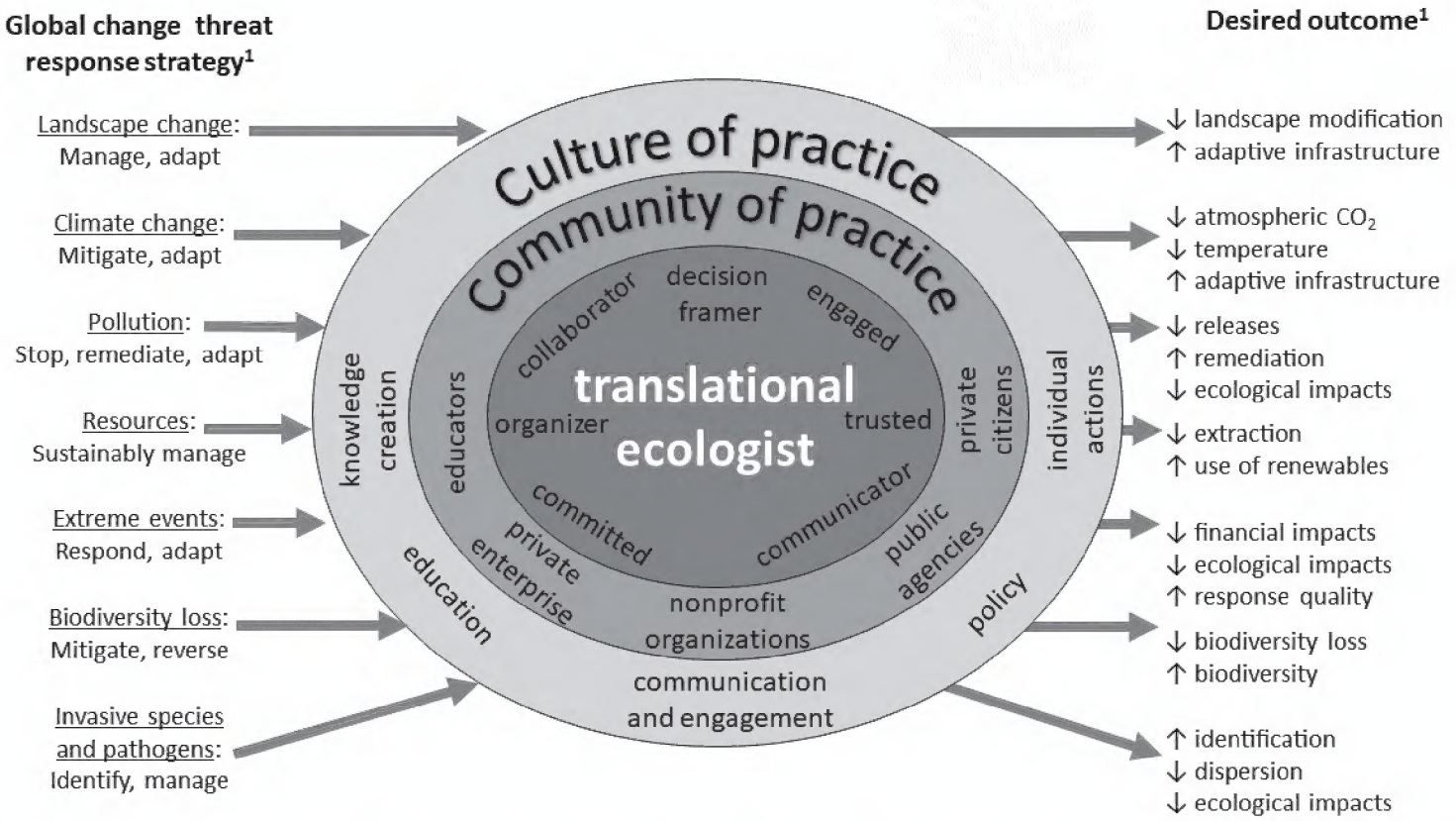

Figure 1. Many translational ecologists possess professional attributes that empower them to play a central role in converting resilience-building strategies into meaningful outcomes by serving as boundary spanners in a community of practice, and by cultivating a broader culture of practice. [1]Summarized from Table 1. Professional attributes (inner circle) were adapted from the "principles and related goals of translational ecology" enumerated by Enquist et al. (2017).

Translational science is imperative to forging inclusive, goal-oriented coalitions of stakeholders that are guided by theories of change and empowered by methodologies to rapidly and expansively co-create resilience to global change threats in ecological, social, and political contexts (Enquist et al. 2017; Ripple et al. 2017; IPCC 2018). Here, we encourage ecologists (and other people in similar positions) to engage more fully in translational actions addressing the seven major resilience challenges (Table 1; Figure 1), by proposing a framework (Figure 1) that lowers barriers to participation (Table 2) and promotes stronger relationships among stakeholders (Figure 2). We conclude by recommending specific actions that ecologists can take based on their capabilities, as well as evidence and demonstrated need.

Relationships are an imperative bridge to resilience

A synergy of policy, communication, research, and action is vital to creating the rapid, just, and expansive changes needed to build resilience (Guston 1999; NRC 2009; Dilling and Lemos 2011; Anguelovski et al. 2019). Policies will be more effective when their goals, rationale, and implementation are guided by evidence. Furthermore, policies should be developed in collaboration with stakeholders, including practitioners and members of the communities affected by those policies (Gibbons et al. 2011; Parsons et al. 2015; Fitzgibbons and Mitchell 2019; Posner and Cvitanovic 2019; Adler 2020). Networks

Table 2. Strategies for overcoming barriers to engagement of translational ecologists in building resilience to global change threats.

Barrier	Strategies to overcome barriers to engagement in translational ecology
Time constraints (Whitmer et al. 2010; Singh et al. 2014)	1) Decrease workload requirements in other areas 2) Require percentage of time committed to translational activities 3) Identify and pursue synergistic activities
Institutional constraints (Whitmer et al. 2010; Singh et al. 2014)	1) Shift institutional priorities to support engagement in translational activities 2) Provide human and infrastructural resources that favor engagement in translational activities 3) Implement a strategic framework for collaboration and continuity of work
Cultural norms (Singh et al. 2014)	Create a workplace culture that supports and rewards engagement
Pressure to publish (Hallett et al. 2017)	1) Relax publication requirements 2) Allow documented activities in translational ecology to count in place of publication requirements 3) Apply qualitative evaluation metrics that equitably account for challenges and timelines associated with translational ecology
Policy limitations (Hallett et al. 2017)	1) Implement policies that incentivize engagement in translational activities 2) Eliminate or revise policies that disincentivize engagement in translational activities
Risk aversion (Hallett et al. 2017)	Implement strategic framework that balances high-risk but potentially high-impact activities with lower-risk, routine activities
Financial constraints (Hallett et al. 2017)	1) Increase funding availability 2) Communicate funding opportunities to employees 3) Support pursuit of funding (e.g., grant writing)
Pressure to act (Hallett et al. 2017)	Develop communities of practice and demonstrate their efficacy at achieving rapid, reliable outcomes

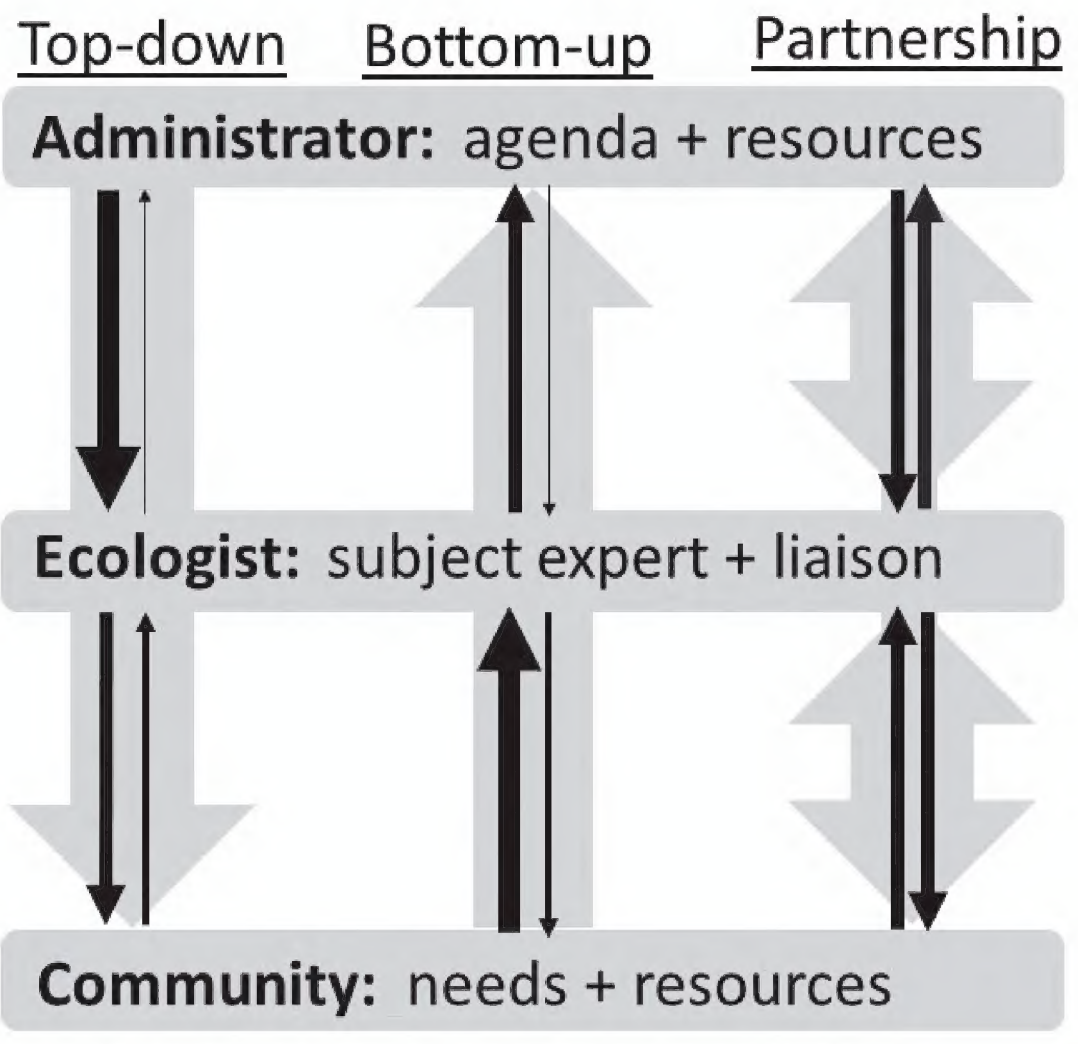

Figure 2. Ecologists' roles in resilience networks. Arrows represent the flow of resources (e.g., money, information, labor, infrastructure, communication); large grey arrows represent the average direction of resources, and small black arrows represent the direction and approximate magnitude of resources transferred between administrators, subject experts, and communities.

of practitioners (e.g., policymakers, educators, engineers, advocates, natural and social scientists) with strong community engagement create synergy between policy, communication, education, research, and actions, which is vital to strategic resilience building (e.g., Spoth and Greenberg 2005; Conrad and Hilchey 2011; France and Compton 2012; Virji et al. 2012; Melillo et al. 2014; Rist et al. 2015; Self et al. 2016; Patel et al. 2017; Ultee et al. 2018; Climate Center 2019; Knoepke et al. 2019; Krisberg 2019; Posner and Cvitanovic 2019). Recognizing the power of an equitable and holistic approach to resilience building, organizations such as the Union of Concerned Scientists, Global Council for Science and the Environment, and 350.org are embracing strategies that build relationships with communities that are frequently disempowered, through education and outreach, support of public officials who endorse science-informed policies to address global change threats, and/or forging alliances with scholars and practitioners to increase access to vital expertise.

Collaboration builds resilience by cultivating communities of practice that are grounded in relationships of trust, inclusion, and equity (Lynn 2000; Coleman and Stern 2018; Harris et al. 2018; Lacey et al. 2018; Lavesque et al. 2019; International Science Council 2020; Potsdam 2020). Collaboration also increases capacity to overcome challenges posed by green "climate gentrification" (which can systematically exclude underrepresented populations from the benefits of green infrastructure), insufficient funding, inadequate administrative capacity, difficulties in sustaining participation, excessive stakeholder workloads, lobbyist influence, frustration with the inability of science to give definitive answers, and communication barriers (Nyden and Wiewel 1992; Israel et al. 1998; Sclove et al. 1998; Campus Compact 2002; Andrews et al. 2005; Spoth and Greenberg 2005; Addison et al. 2013; Bromham et al. 2016; Wehn and Almomani 2016, Allen et al. 2018; Anguelovski et al. 2019). However, collaboration across cultures and professions can be daunting because of differences in language, value systems, traditions, conflicts over power and resource sharing, inequalities, distrust, historical and present-day trauma, misapplication of science, tokenism, and misconceptions about science and the experience and knowledge of stakeholders (Lynn 2000; Oreskes and Conway 2010; Harris et al. 2018; Fitzgibbons and Mitchell 2019; Jurjonas et al. 2020). Strong, trust-based relationships characterized by sustained, consistent, clear, and empathetic communication (Lave and Wenger 1991; Milkoreit et al. 2015) are foundational to resilience building and must be supported by strategic long-term investments (e.g., Kelly 2003; Spoth and Greenberg 2005; Virji et al. 2012; Bremer and Meisch 2017; Cvitanovic et al. 2018; Lemos et al. 2018; Schwarz et al. 2019). Such relationships are critical to the inclusion of historically marginalized communities in the crafting of solutions to global change threats. For example, underrepresented coastal communities in the Pacific Northwest and Louisiana are leveraging their relationships with scientist partners to develop climate change adaptation plans (Tulalip 2017; LASAFE 2019). Given the need for reliable scientific information and expertise to effectively understand, frame and address the impacts of global change, there are great needs and opportunities for science practitioners to partner with other stakeholders including the general public.

The cultivation of co-productive partnerships must be informed by effective, transparent, and collaborative methods (Merson et al. 2018; Firestone et al. 2020). Such partnerships are exemplified by the Youth Climate Movement, in which science professionals play a supporting role in the efforts of young climate activists advocating for broad responses to global change (Fisher 2019). The power of these partnerships is amplified when grounded in best-practices, coordinated through public, private and nonprofit institutions (e.g., Spoth and Greenberg 2005; Parsons et al. 2016; Coleman and Stern 2017; Posner and Cvitanovic 2019), and guided by a theory of change (Weiss and Connell 1995; ORS 2004; Brest 2010). A theory of change is a methodology used to plan for long-term outcomes by defining shorter-term actions in a framework that makes explicit the rationale, goals, assumptions, strategies and assessments of those actions (Weiss and Connell 1995; ORS 2004; Brest 2010).

Ecologists' resilience building partnerships should be guided by a theory of change. In translational ecology, a theory of change should emphasize collaboration, engagement, commitment, communication, trust, process, and decision framing (Enquist et al. 2017; Lawson et al. 2017) – all of which align with the principles guiding partnerships with Indigenous communities (i.e., respect, relationship, reciprocity, responsibility [Bell, 2013]). A theory of change for collaborative resilience building should (a) embrace existing partnerships, socio-cultural values and knowledge structures; (b) encourage engagement of stakeholders from under-represented groups (e.g., Black, Indigenous, and People of Color (BIPOC); LGBTQIA+; those with disabilities; those experiencing homelessness; and undocumented persons) in knowledge co-production; (c) critically evaluate the interrelationship and embeddedness of societies within nature; (d) seek to alleviate inequity; (d) resolve gaps between actual and perceived risks that impede changes in human behavior; and (e) insure equitable data governance (Arnstein 1969; ORS 2004; Cisneros-Cohernour et al. 2007; Virji et al. 2012; Milkoreit et al. 2015; Lidskog and Waterton 2016; Wall et al. 2017a; Ramirez et al. 2018; Fitzgibbons and Mitchell 2019; Nuñez et al. 2019; Research Data Alliance 2019; Dietz et al. 2020). For these reasons, many organizations and initiatives supporting responses to global change threats (e.g., the Climate Center, 350.org, Sierra Club, Intergovernmental Panel on Climate Change, Scientists Warning, Xerces Society, The Nature Conservancy, The Sunrise Movement) are guided, implicitly or explicitly, by a theory of change.

To articulate the functional importance of ecologist-community partnerships in building community resilience to global change threats, we examine three broad resilience building perspectives: 1) top down, 2) bottom-up, and 3) partnership (Figure 2). We characterize each perspective in terms of the predominant flow of resources (e.g., funds, communication, and human and infrastructure resources). Each perspective has three major categories of stakeholders: administrators (e.g., executive or public official), subject experts (e.g., ecologists, engineers, educators), and the community (i.e., the general public). We acknowledge that in most scenarios, all three perspectives co-exist to varying extents.

In the top-down perspective, an administrator identifies a challenge and enters into a contract with a subject expert to address the challenge. Here, the ecologist acts as

a consultant/contractor by requesting resources from the administrator to perform a function at the administrator's direction; ultimately, the resources are channeled into a "solution" that is imposed upon a community with little or no feedback from the community to the administrator. The "solution" imposed upon the community may be inappropriate, damaging, or at best poorly-received due to lack of community input (Robbins 2011). The subject expert's actions or lack thereof depend entirely on the administrator's directives, so the impact on the community is at the behest of the administrator. Although paradigms are shifting, a top-down approach has traditionally been employed by the U.S. Environmental Protection Agency Superfund program (United States 1980), which directs public and private funds to remediate contaminated sites, often in conjunction with a private remediation contractor.

In the bottom-up perspective, the community (or a representative thereof) identifies a challenge and solicits support from the administrator and/or subject expert to resolve it. The administrator may enlist the subject expert, or the subject expert may approach the administrator for resources or policy changes, but the primary flow of resources is from the community to the administrator. Limitations in the community's capacity to provide or direct the flow of resources can impede success; however, even limited success can provide a community with a sense of empowerment. The success of these types of bottom-up, community-driven or "grassroots" initiatives depend on consistent, impactful, collective advocacy and management of resources, which can create substantial time, financial, and logistical burdens for a community. A number of nonprofit organizations, such as the Louisiana Bucket Brigade (2020), have been founded to represent and empower communities impacted by environmental issues, providing access to subject experts and defraying the emotional, physical and financial costs. However, the abundance and reach of such organizations are often limited.

In the partnership perspective, a person who is prepared to strategically coordinate communication, resources and agendas across community and administrative levels fosters holistic co-creation of solutions to global change threats. Such a boundary spanner can empower and mobilize communities to participate in building their own resilience. Partnerships, as we elaborate upon in the subsequent section, have strong potential for long-term success. But, results can be slow and iterative to achieve, as much time must be devoted to building relational contracts. Broadly-trained ecologists who are versed in science, management, mediation, diplomacy, social learning, and working across different knowledge systems are needed to identify and translate the needs expressed by members of a community into an evidence-informed action plan or theory of change, and strategically coordinate with administrators to direct resources toward implementing the plan (Safford et al. 2017; Schwartz et al. 2017). By working bidirectionally with communities and administrators, ecologists can serve as liaisons and impartial subject matter experts, forging strong relationships with both stakeholder groups and successfully negotiating the inevitable conflicts over funds, priorities, and community interests. For example, two retired environmental engineers (with substantial ecological knowledge) representing Friends of Cross Lake (2021), an organization of camp owners in northern Maine, have used town hall meetings, dona-

tion drives, and education initiatives to gain the support of their local community to undertake efforts that improve water quality in their shared lake, and simultaneously used their grant writing experience to secure State and Federal funding and approvals to make landscape changes that mitigate inputs of phosphorus into the lake. In this situation the environmental engineers were embedded both within the local situation and larger contexts, allowing them to be effective boundary-spanners.

Translational ecologists' vital roles in collaborative resilience building

Ecologists and other transdisciplinary scientists play vital roles in addressing complex socio-environmental challenges such as building resilience to global change threats (Schlesinger 2010; Enqist et al. 2017; Krisberg 2019). There are many recommendations for how ecologists can engage successfully with communities to address environmental challenges. These recommendations emphasize clear and consistent communication, knowledge co-creation, broad stakeholder participation, and evidence-based practices (e.g., Reid et al. 2009; Tengö et al. 2014; Fernández-Giménez et al. 2019). Examples from a presentation series on ecologist-community partnerships at the 2019 Ecological Society of America (ESA) conference fell into four general categories: the process of partnership-building (Marshall 2019; Potter 2019; Shmaefsky 2019; Thomas 2019), using media to garner support for conservation (Kaoma 2019; Theune 2019), building socio-ecological resilience of communities to global change threats (Carey 2019; DeCaro 2019; Jurjonas et al. 2020), and protection of natural resources (Wilson 2019). Forums such as townhall meetings, presentation sessions, webinars, and workshops that bring together practitioners, community leaders, advocates and activists around a common theme raise awareness and create pathways for broadening participation. For example, ESA has hosted such events at recent annual conferences (e.g., Rubert-Nason et al. 2017; Casper et al. 2018; Pouyat et al. 2018; Mourad et al. 2019; Schwarz et al. 2020) to encourage networking and collaboration of ecologists across disciplines. The American Geophysical Union's Thriving Earth Exchange demonstrates another promising framework for facilitating transdisciplinary science, acting as a clearinghouse to connect community organizations with scientists and to train partnering scientists in effective community-led collaboration (Thriving Earth Exchange 2021). However, these actions represent only a first step, as the ultimate goal of knowledge co-construction must be to integrate the perspectives of community members, scientists and other stakeholders (Tengö et al. 2014).

Integration of these perspectives may be accomplished through the creation of a community of practice (e.g., the Climate and Resilience Community of Practice [http://masgc.org/climate-resilience-community-of-practice/] and the Resilient Cities Network [https://resilientcitiesnetwork.org]). A community of practice that equitably represents various stakeholders (e.g., educators, private enterprises, nonprofit organizations, public agencies, and private citizens) in the process of knowledge co-construction should be centered in a broader culture of practice that addresses five key dimensions

of resilience-building: communication and engagement, policy, education, knowledge creation and curation, and individual actions (adapted from Climate Center [2019]) (Figure 1). We do not expect that all ecologists' areas of expertise will intersect with all five dimensions, but rather that most ecologists' activities intersect with one or more of these dimensions. We encourage all ecologists to identify opportunities within their own work to engage more deeply with the dimensions for collaborative resilience building that are most-aligned with their areas of expertise. And, we provide a list of challenges and recommended actions that ecologists can take in each of these five dimensions (Table 3).

Communication and engagement create the relationships, networks, and coalitions that empower people to build resilience by increasing trust among stakeholders, establishing credibility, salience, and legitimacy of resilience initiatives, and empowering people to demand equitable and inclusive policies. Transparent, sustained communication should take place through trusted channels, and include as many stakeholders as possible in discussions of expectations, outcomes, funding, and time constraints (Bidwell 2016; Merson et al. 2018; Dietz et al. 2020; Firestone et al. 2020). Pathways for broad, equitable stakeholder participation and knowledge co-production are essential (Merson et al. 2018; Dietz et al. 2020; Firestone et al. 2020), and should include those who are frequently left out. As part of this process, local, traditional and Indigenous knowledge systems must be valued and respected (Bell 2013; Tengö et al. 2014; David-Chavez and Gavin 2018). Institutions such as university extension programs, government initiatives with a focus on extension such as NOAA's Regional Integrated Sciences and Assessment (RISA) program (NOAA 2018), and nongovernmental organizations exemplify amplifying science delivery through communication and engagement, and have great potential for creating changes that overcome global change threats (Cash et al. 2003). These institutions serve as boundary organizations, facilitating constructive collaboration between scientists, stakeholders, and the public (Graham and Mitchell 2016; Gustafsson and Lidskog 2018; Selzer et al. 2020). Moving forward, boundary organizations that have not yet done so should prioritize building equity into their communication and engagement activities, recognizing (for example) that nearly 90% of climate change research that accesses Indigenous knowledge has been extractive rather than collaborative or co-constructed (David-Chavez and Gavin 2018).

Policies are needed to create pathways for equitable resilience building through funding, creation of infrastructure, human resources, education, research and development, and stakeholder relationships. Policies must be developed, interpreted, and implemented in ways that are equitable, rational, inclusive and participatory, and aim to create resilience-oriented communities of practice (Vogel et al. 2007; Reed 2008; Richards and Den Hoed 2017; Fitzgibbons and Mitchell 2019; Posner and Cvitanovic 2019). These objectives can be met by co-creation of policies with the communities served, through structured decision making, systematic prioritization, and partnership with acculturated practitioners who are trusted in their communities so that outcomes are more than a superficial effort (Runge et al. 2013; Rigolon et al. 2019). Key to recruiting acculturated practitioners is a shift in the professional culture of the eco-

Table 3. Five dimensions in which translational ecologists can engage in meaningful actions to overcome challenges to building resilience to global change threats.

Dimension	Challenge	Action	Desired outcomes
Communicat-ion and engagement	Goal achievement impeded by lack of communication, motivation, inclusion, and representation, and by frustration with inability of science to provide rapid, definitive solutions	1) Forge coalitions that empower communities to obtain equitable and inclusive resilience building policies 2) Develop relationships of trust with communities and their leaders (especially those who are underrepresented and/or have experienced trauma) 3) Leverage professional expertise and/or status to advocate for the credibility, salience, and legitimacy of evidence-based resilience initiatives 4) Accurately identify and communicate community needs/interests to administrators	*Specific*: Stronger relationships, networks, and coalitions are created that empower people to build resilience; knowledge/technology is applied to build resilience *Broader*: Communities of practice are empowered to collaboratively address the grand challenges in resilience building
Policy	Policies do not adequately support goals, and/or lead to unintended/inappropriate consequences	1) Co-create policies 2) Consulting/make policy recommendations (e.g., serve on review panel, provide editorial advice) 3) Critically evaluate policies and their effectiveness 4) Critically evaluate the interpretation and enforcement of policies	*Specific*: Funding, infrastructure, knowledge, technology, education, human resources, and strategic relationships are directed toward building resilience *Broader*: Policy impacts are just, equitable, inclusive, evidence-informed, and effectively address the grand challenges in resilience building
Education	Misconceptions and lack of awareness, conceptual, and practical understanding of challenges by administrators and communities impede goal achievement	1) Serve as formal educators in science, technology, engineering, arts and math (STEAM; preK-18) 2) Serve as informal educators (e.g., guides, docents, university extensionists, community scientists and community science trainers) 3) Create learning communities in physical and virtual spaces that promulgate action-oriented conversations focusing on just and equitable science delivery 4) Foster social learning 5) Workforce preparation for ecologists and future workers (Schwartz et al. 2017)	*Specific*: There is expansive promotion of a socio-ecological narrative that: 1) Acknowledges the causes and consequences of global change 2) Embraces evidence-based decisions in mitigation of and adaptation to global change threats 3) Permits and values participation by *all* people in policy, planning, and decision-making 4) Supports accountability 5) Encourages observation, reflection, and transfer of knowledge *Broader*: *All* people are empowered with the knowledge and skills to address the grand challenges in resilience building through participation in science and democracy
Knowledge creation and curation	Technology and best practices that support resilience goals are not implemented; inadequate capacity for knowledge creation and implementation	1) Conduct fundamental research that increases theoretical understanding of the causes and consequences of global change 2) Develop technology and practices that enable mitigation of and adaptation to global change 3) Devise strategies for expansive implementation of theoretical, technological, and applications knowledge for mitigation of and adaptation to global change, including building stronger ecologist-community partnerships 4) Create new theoretical frameworks and philosophies for embracing diversity, equity, inclusion, and justice	*Specific*: Improved prediction of global change consequences; widespread implementation of mitigation and adaptation strategies that preserve human life, well-being, biodiversity, and ecosystem function *Broader*: Foundational knowledge, technologies and best practices are accessible to effectively address the grand challenges in resilience building
Direct, individual actions	Lack of personal motivation, sense of empowerment, and actions supporting resilience goals; lack of ecologist engagement in translational science	1) Serve as leaders and role models 2) Help communities/leaders identify credible information, access relevant research, conduct risk assessments, serve as subject matter experts, secure funding, and educate community members, media and policymakers about salient issues 3) Organize and/or participate in democratic actions (i.e., protests, civil disobedience) 4) Deescalate tensions through the use of clear, consistent, and empathetic communication of evidence-based knowledge in a culturally salient context 5) Incentivize ecologist and institutional engagement in translational science (Hallett et al. 2017)	*Specific*: Every public citizen embraces lifestyle changes, role modeling, advocacy, activism and leadership actions that build a collective culture of resilience *Broader*: A normalized culture of resilience (grounded in principles of equity, inclusion, justice, compassion and evidence-based best practices) creates a sustainable trajectory toward addressing the grand challenges in resilience building

logical community to support policies that fund and promote workforce diversity, equity, and inclusion through practices such as mentorship, networking, and training that are specific to underserved communities (O'Neill and Gomez 1996; Andrews et al. 2005; Dilling and Lemos 2011; Virji et al. 2012; Tancoigne 2019; Arnott et al. 2020). A collection of recommended climate change mitigation policies that can be devised and implemented in accordance with these criteria, and which are likely to gain public acceptance, are described by Krosnick and MacInnis (2020). Ecologists can engage directly in policymaking by not only sharing their knowledge and advocating for science-informed policies, but also by following the CARE principles for Indigenous Data Governance (Research Data Alliance International Indigenous Data Sovereignty Interest Group 2019), including ethically amplifying the traditional ecological knowledge that community partners contribute (Rosenberg 2007; Young et al. 2014; David-Chavez 2019).

Education empowers people to build resilience by changing the socio-ecological narrative by creating awareness, supporting knowledge co-production, fostering implementation of high impact practices, conveying hope, and sharing ideas. Education equips individuals to understand causes and consequences of global change and the goals of resilience-oriented actions, participate in policy development, hold each other accountable, and educate others. Educating activists can work on multiple levels, for example, by educating policymakers to make meaningful legislative impact (Climate Center 2019), and by educating youth to impact the behavior of both future generations and parents (Lawson et al. 2019). Strategic coordination of education initiatives among pre-college, college and community-based programs, through internships, co-generative dialogues, community science, parks/museums, co-instruction, and research on teaching and learning has the potential to widely expand global change literacy (Andrews et al. 2005; Hsu and Espinoza 2018). Extensionists, applied researchers, and practitioners have been encouraged to increase their engagement with communities (France and Compton 2012; Devonshire and Hathway 2014), especially those with identities that are frequently marginalized. Educational practices will be more effective when rooted in culturally-relevant practices that critically engage with the way that Western Modern Science is "neutralized" and unwarrantedly marginalizes other knowledge systems (Wilson 2008). As part of the situated nature of science and engineering, questions surrounding benefit, harm, and tradeoffs are usually considered from limited perspectives. This process should be informed by feedback from learners, integration with local and traditional knowledge, and supported through increased training among practitioners (David-Chavez 2019). Boundary-spanning organizations such as Bringing Theory to Practice (https://bttop.org/) and the Maine Environmental Education Association (https://www.meeassociation.org/) promote innovative pathways for educating community leaders, activists, youth, concerned citizens and others about global change issues. Ecologists can support education through teaching, developing educational materials, evaluating existing educational programs, and serving as advocates, mentors and information sources for students, teachers, science outreach organizations and advisory boards (Bybee and Morrow 1998; Andrews et al. 2005; Thomas et al. 2019).

Knowledge creation and curation increases awareness of global change challenges, advances understanding of global change causes and consequences, generates technology that builds resilience, and develops methods that bring theory and technology to practice. A theory of change that takes into account the resilience needs and perceptions of diverse communities, and prioritizes equitable stakeholder engagement and knowledge co-production should guide resilience-building initiatives (Arnstein 1969; Brest 2010). It is critical that ecologists engage in interdisciplinary, co-constructed research that views global change through the lens of coupled socio-ecological systems, that acknowledges the limitations of an exclusively Western Modern Science viewpoint, and encompasses multiple ways of knowing (Wilson 2008; Tengö et al. 2014). This will entail studying the drivers and consequences of global change and resilience for humans and ecosystems, evaluating peoples' perceptions of global change risks and their influence on policy and practice, evaluating the efficacy of practices such as participatory decision making (Reed 2008; Newman et al. 2017; Stern and Wolske 2017; Nicolosi and Corbett 2018; Posner and Cvitanovic 2019; Sellers et al. 2019; Dietz et al. 2020), creating and implementing technology (e.g., Guston 1999; Hawken 2017; Ripple et al. 2017), advancing methodology for cultivating more inclusive and equitable partnerships among stakeholders and culturally-informed coalition building, and advancing methods in defining, accessing, sharing, and applying science data in policy (Reed 2008; Virji et al. 2012; Wilkinson et al. 2016; Wall et al. 2017b; Akerlof 2018; Posner and Cvitanovic 2019; Research Data Alliance 2019; Dietz et al. 2020). Ecologists can extend the reach of their actions through frameworks that facilitate strategic coordination of research between institutions (e.g., Essential Biodiversity Variables initiative [Pereira et al. 2013], the Long-Term Ecological Research Network, and the National Ecological Observatory Network), contributing to research synthesis (Cooper et al. 2019), and participating in collaborative assessments (e.g., Hood et al. 2015; Brondizio et. al. 2019).

Direct, individual actions, such as personal lifestyle changes, role modeling, advocacy, activism and leadership create a culture of global change resilience (Stern and Wolske 2017; Climate Center 2019). Advocates and activists draw broad attention to key issues and may also serve as critical liaisons with communities impacted by historical trauma and ongoing inequities. Forging a community of leadership among activists, advocates and practitioners keen to represent the public interest has great potential to galvanize policy changes, knowledge sharing and co-creation, empathy, healing, relationship building, and social cohesion. Ecologists can serve as leaders and role models in many ways: by helping stakeholders identify credible information and access relevant research, conducting risk assessments, serving as subject matter experts, securing funding, and through dialogue that provides a scientific perspective to community members, media and policymakers about salient issues. Many science-focused organizations (e.g., Union of Concerned Scientists, Ecological Society of America, American Association for the Advancement of Science, American Geophysical Union's Thriving Earth Exchange, Global Council for Science and the Environment, and the Association for the Advancement of Sustainability in Higher Education) provide resources to help scientists engage in direct actions and build relationships with stakeholders and support resilience building.

Conclusions and recommendations

Ecologists and other people engaged in translational science, as experts who are accustomed to working among diverse subjects and stakeholders, play vital roles in creating global resilience through their contributions to communication, policy, education, knowledge creation and individual actions. The field of ecology is rapidly moving towards a focus on transdisciplinarity, but there is more to be done. In her speech before the U.N. Climate Council (2019), activist Greta Thunberg implored international leaders to heed the warnings of *scientists* regarding imminent global change threats and how to address those threats. Facing a convergence of existential threats posed by environmental change and compounded by pandemics, injustice and inequity, it is ecologists' duty to identify, strengthen, and participate in opportunities that translate their work into meaningful actions through cultivation of equitable, inclusive, empathetic, and just relationships among stakeholders. Ecologists' partnerships with communities are an imperative bridge to creating socio-ecological resilience to global change through actions that create equitable and science-informed policies, combat misinformation, empower people with problem-solving skills, protect and expand the process of knowledge creation, encourage empathy and community-mindedness. We call for immediate action, because the role of science in our society is being diminished by deliberate misinformation campaigns, despite the urgent need to implement evidence-based practices to address climate change, pollution, biodiversity loss, and emergent pathogens, and ultimately ensure the sustainability of life on Earth. Ecologists have the power to bolster public trust in science and build communities of practice that can function as local networks of expertise and preparedness, operate independently of centralized administration, and enable rapid, high-impact responses to global change disruptions.

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